National Aeronautics and Space Administration

AIRSPACE SYSTEMS PROGRAM

NEXTGEN

Beyond NextGen: AutoMax Overview and Update

Parimal Kopardekar, Ph.D. and Natalia Alexandrov, Ph.D.

NextGen Concepts and Technology Development Project

www.nasa.gov

Outline

- Main Message
- National Airspace System State of the Art
- Need for Auto Characteristics for Airspace Operations System
- AutoMax
  - Goals, Scope, Motivation and Potential Benefits, Examples Directly Applicable to Airspace Operations
- Research: Questions, Design Approach, and Needed Capabilities
- Enabling Capability: SMART NAS
- Challenges
- Progress, Products and Metrics
- Summary

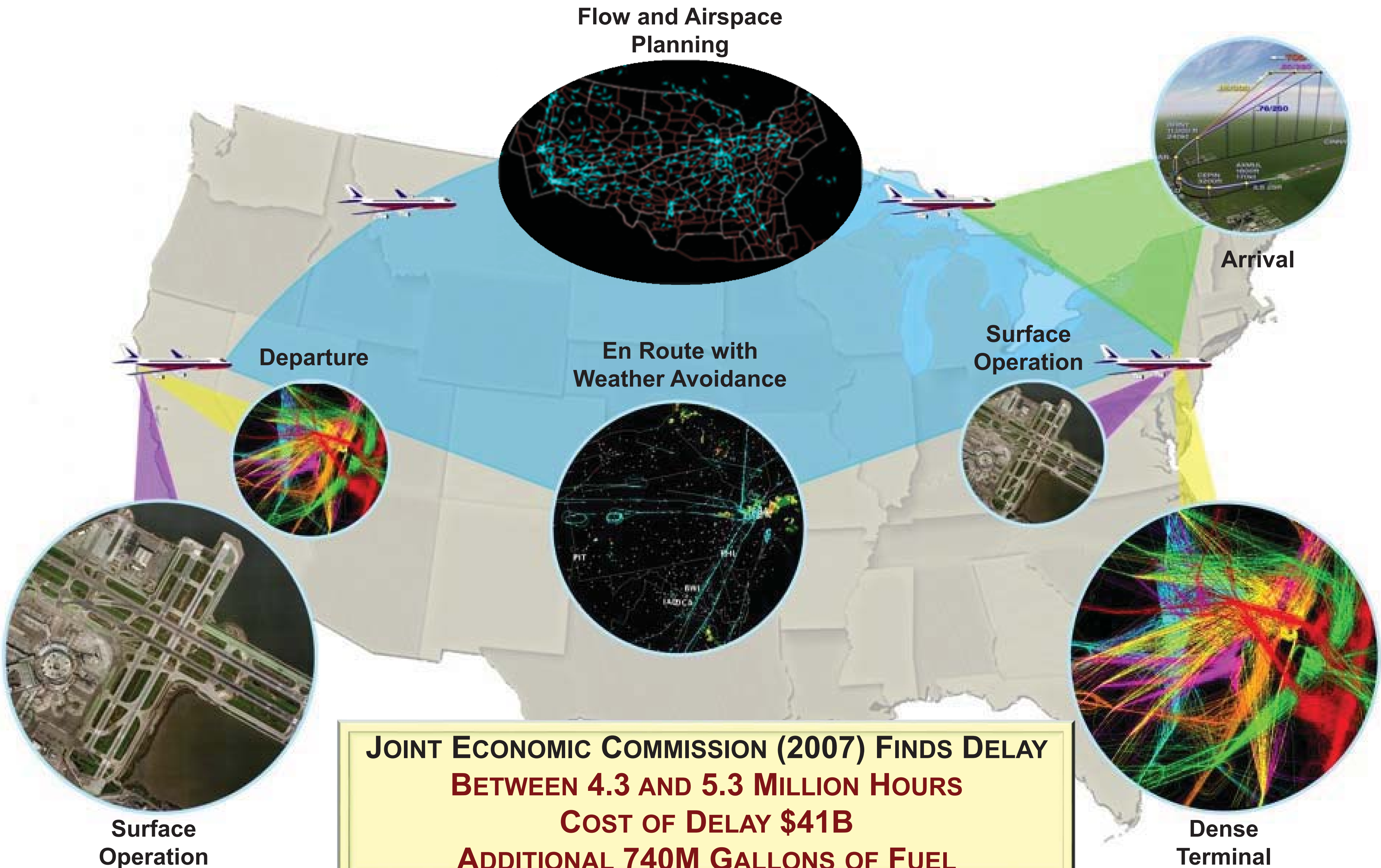
Research Planning is in Progress

Main message

- National and Global Needs
  - Develop scalable airspace operations management system to accommodate increased mobility needs, emerging airspace uses, mix, future demand
  - Be affordable and economically viable
- Sense of Urgency
  - Saturation (delays), emerging airspace uses, proactive development
- Autonomy is Needed for Airspace Operations to Meet Future Needs
  - Costs, time critical decisions, mobility, scalability, limits of cognitive workload
- AutoMax to Accommodate National and Global Needs
  - *Auto*: Automation, autonomy, autonomicity for airspace operations
  - *Max:* Maximizing performance of the National Airspace System
- Interesting Challenges and Path Forward

Drivers - Mobility, mass operations, money, maximizing performance

State of the Art
Gate-to-Gate Concepts and Technology



JOINT ECONOMIC COMMISSION (2007) FINDS DELAY
BETWEEN 4.3 AND 5.3 MILLION HOURS
COST OF DELAY $41B
ADDITIONAL 740M GALLONS OF FUEL

State of the Art
Barriers To Meeting Air Transportation Needs

- Operational efficiency and airspace complexity (diversity, volume, capacity) are constrained by human workload limitations
- Limited automation and decision support tools lead to suboptimal decisions and inefficiencies
  - Surface, arrival, departure, and metroplex operations
  - Sector based rather than trajectory based
  - Uncertainties
  - Limited number of aircraft handled in a sector
- Limited ability to simultaneously provide safe (keeping aircraft separated), efficient (fuel and environment), and expeditious (fewer delays) flow
  - Particularly under high density conditions, where focus shifts to safety and expediency, while efficiency suffers
- Current system is not adequate to meet future needs

Current barriers include limited automation and cognitive workload

Need for *Auto* characteristics in Airspace Operations System – Safety, Efficiency/Scalability, & Mobility

- **Human simply executes automation guidance where rapid decisions and execution is needed –** Traffic Collision Avoidance System (TCAS)
- **Rare normal events may lead to human skill degradation** – Aircraft stall management
- **High complexity leads to suboptimal human decision making –** safe, expeditious, and efficient operations
  - Probabilistic weather, multiple constraints *(too much information for humans to make sound decisions)*
  - Arrival, departure, and surface operations optimization *(too much information and not enough time)*
  - Metroplex traffic management *(required precision and combinations are too high for human capability)*
- **High workload limits capacity and throughput –** Human workload limits number of aircraft
- **Human-centric system costs limit mobility –** Air taxi/On-demand aircraft with two pilots or personal air vehicles requiring piloting skills
- **Labor cost differences impact competitiveness** – Huge cost difference in global economy
- **Enable new operations with high productivity** – Low altitude UAS operations

Need for auto enablers due to complexity, diversity, demand, costs pressures, and newer needs

AutoMax Goals

- Increase **mobility** of passengers, goods, and services
- Allow **diverse** vehicle mix and airspace uses (e.g., air travel, wind turbines, commercial space launches)
- Enable **scalability** to accommodate future demand
- Accommodate a variety of **business models** (e.g., hub-and-spoke, point-to-point, air taxi, sharing, etc.)
- Maintain highly efficient, predictable, agile, scalable, and **affordable** airspace operations system
- Maintain global **competitiveness** and domestic viability by innovation in technology and business models to manage airspace operations

AutoMax is a research initiative aiming to achieve above goals using justifiable and optimal combination of *"auto"* characteristics for management of future airspace operations

AutoMax aims to accommodate future mobility, diversity, business models with scalable and sustainable operations

Examples of *Auto* Properties for Airspace Operations

- Autonomicity: system focused self-management, technologies for
  - *Self-configuration*: Capacity-to-safety transition in operations (two extremes, such as Microsoft Windows normal mode vs. safe mode)
  - *Self-optimization*: Optimization based on changing conditions in traffic, weather, and disruptions
  - *Self-protection*: Anomaly detection (e.g., GPS degradation) and reaction; e.g., lower position accuracy leads to increased buffers and reduced capacity
  - *Self-healing*: Recovery from degradation
- Autonomous operations and autonomy technologies for
  - Non-towered airports, flow management, unmanned vehicles, personal and passenger air vehicles
- Automation Technologies
  - Conflict detection and resolution, route planning, severe weather avoidance, reduced crew operations, remotely operated vehicles

Increased "auto" automation, autonomy, and autonomicity are needed to meet future needs

Important Research Questions

- What is the overall design that enables safe, scalable, sustainable, affordable mobility options for future
- How should control be distributed between human and auto (e.g., dynamic and adaptive locus of control)? What are the ideal human roles?
  - Relying on human limits scalability vs. unexpected management of operations
- What are the functional and networking architecture design options that are scalable, modular, extensible to meet future capability needs?
- What are the performance improvements, cost, and benefits that justify AutoMax need?
- What are the nominal and off-nominal, degraded conditions under which AutoMax must function?
- What verification, validation, and certification methods enable *auto* properties based operational system?
- What is the transition path of the system from current operations to future?
- What is the most effective approach to change management and acceptance of a system that is based on auto properties?

Adaptive levels, design, performance, cost/benefits, V&V, and change management are areas of research

Two-Pronged Approach

- Overall design – *ab initio* or clean sheet
- Develop specific targeted capabilities to address needs

Approach 1: *Ab Initio* or Clean Sheet Design

- Need research rather than a priori decision on human/machine role which may lead to premature point design
- Develop rigorous system design approach for optimal design to address performance
- Functions, allocations, sensors, data analytics, redundancies, CNS, vehicle/system interaction, software, human interfaces, etc.
  - Be forward and backward compatible to the extent possible
  - Offer adaptive autonomy and locus of control for human-machine interaction
  - Offer plug-and-play so that future trends can be accommodated by additional technology evolutions
  - Possess sufficient intelligence to ensure appropriate response to unanticipated events under uncertainty
    - State of the art in machine intelligence may not be adequate

Ab initio design considerations

Challenges

- Technology development for larger-scale air traffic management – lessons learned from prior efforts (e.g., AAS, AERA)
- Verification and validation of systems and technology providing autonomicity
- Assured safety of autonomous operations
- Certification of auto enabled systems
- Role of humans (adaptive automation, how much) – Cognitive echelons
- Harmonized transition from current NAS to AutoMax future
- Cyber physical security
- Social acceptance of *auto-based* systems and operations
- Legal considerations about responsibility of undesirable event

Examining AutoMax Concepts, Algorithms, and Technologies: SMART NAS

- New simulation capability called Shadow Mode Assessment using Realistic Technologies for the National Airspace System (SMART NAS) is being developed
- Motivation
  - General agreement that National Airspace System (NAS) needs to transform, and the pace of transformation is rather slow
  - NAS is a complex system with high safety requirements
    - Results in incremental and evolutionary changes that are validated
  - Such incremental upgrade approach is rather slow and does not consider integrated operations efficiently – could take many decades to get to “true” next generation and beyond
- Focused on longer-term concepts exploration and their interactions
  - Functional requirements, information flows, automation/human and air/ground allocations

SMART NAS needed to research and define AutoMax specifics

SMART NAS (continued)

- Objectives
  - Develop approach to faster validation of concepts, technologies and their integration, and future autonomy architectures
  - Reduce the time to validate concepts, technologies and their interactions
  - Provide plug-and-play capability that is modular and based on open architecture principles to compare alternative approaches
  - Provide real-time assessment of technologies as compared with current operations
  - Provide live, virtual, and constructive distributed environment
- SMART NAS capability is a community resource to reach transformed future
- SMART NAS will allow examination of design alternatives, “auto” architectures, variety of roles of human-machine interface
- Open architecture based capability - Opportunity to redesign the airspace operations system using SMART NAS
- Allows examinations of overall design options as well as targeted capabilities

SMART NAS is a community resource to determine future functional architecture(s)

Progress

- Conducted literature review
- **Workshop 1**: Included air traffic management research subject matter experts
  - Goal: Discuss AutoMax needs and identify initial opportunities and approaches
- **Workshop 2**: Included NASA space and exploration system autonomy experts from ARC, DRFC, JPL, JSC, KSC, LaRC, and MFSC
  - Goal: Discuss lessons learned from space and exploration community on the needs of autonomy/autonomous operations
  - Interesting findings: key lessons have similar characteristics
  - Pressures on costs (e.g., multiple successive launches)
  - Communication lags (e.g., 7 minutes of terror for Curiosity landing)
  - Tactical decision making with time criticality (e.g., launch abort)
- **Inter-center research planning team** has been formed; conducted first meeting to identify initial areas; work will continue through December 2013 to develop an initial research plan

Identified opportunities and studied lessons learned

Products

- Concepts/visions that enable divergent views about future
- Design alternatives: trades, analysis, methods, and functional architectures
  - Overall design – *ab initio* or clean sheet
  - Requirements related to architecture, sensors/data/fusion, CNS, reliability, bandwidth, security, safety, human-machine adaptive levels, redundancies, interfaces, etc.
- Safety, costs, benefits, assured autonomy, and certification – justification and methods
- Technology suites and their specifications to show impact with targeted opportunities
- End-to-end AutoMax Live, Virtual, and Constructive Distributive Environment demonstration – validate requirements
- Change management – acceptance and path to deployment
- Overall requirements, roadmap to address future needs and opportunities to improve operations

Identified opportunities and studied lessons learned

Metrics for AutoMax

- Mobility metrics (newer in terms of affordability, commute time, etc.)
- Economic value of airspace use (newer metric)
- Total airspace operations/cost to operate
- Airspace user mobility and access for different types of aircraft/vehicles
- System scalability, capacity, throughput, predictability, resiliency, adaptability
- Cost per passenger mile
- Number of tons of cargo and number of passengers
- On-time arrivals and departures
- Delays, Fuel/energy efficiency, Extra miles flown from optimal path
- Emissions
- Network efficiency
- Accommodation of different types of vehicles operating in the NAS and associated NAS-wide system performance
- Accommodation of different types of business models

Performance metrics to demonstrate AutoMax benefits

Summary

- *NextGen* portfolio focuses largely on efficiency
- *AutoMax* research addresses the future mobility needs, airspace operations needs, and pressures in efficiency and productivity
- *AutoMax* will produce justifiable and optimal *Auto* technologies with opportunities to make impact along the way
- *AutoMax* products will impact in stages and also lead to overall redesigned system
- *SMART NAS* will assist in examination of functional architecture alternatives
- Proceedings of two *AutoMax* pre-planning workshops and a large literature survey relevant to automation and autonomy is now in editing for publication as a NASA Technical Report ; available in Oct-Nov 2013
- *AutoMax* research plan is expected by CY13 – Be back to report

Innovate Relentlessly

Terminology

- **Automation/automated process**: Replace manual process with software/hardware that follow a programmed sequence
- **Autonomy**: Allows participants to operate on their own, based on internal goals, with little or no external direction. Participants can be human or machines. Autonomy implies self-governance and self-direction. Autonomy is a delegation of responsibility to the system to meet goals
- **Autonomicity**[1]: Builds on autonomy technology to impart self-awareness to system/mission, which includes configuration, optimization, healing, protection. These are enabled by self-awareness, self-situation, self-monitoring, and self-adjustment

[1]Truszkowski, W., Hallock, L., Rouff, C., Rash, J., Hinchey, M.G., Sterritt, R. (2009) Autonomous and Autonomic Systems: With Applications to NASA Intelligent Spacecraft Operations and Exploration Systems

Auto in AutoMax refers to combination of all "Auto" properties

Auto Motivation and Benefits

- Ensure global competitiveness for carriers
  - Competition in international market – cost structures are different
- Affordable travel and economic viability for domestic operators
  - Costs: 25% labor and 25% fuel
- Accrue greater economic value from airspace (e.g., UAS goods and service delivery, wind turbines)
  - Lower altitude airspace is underutilized
- Accommodate much larger operations with increased service provider productivity
  - Limits of current system, service provider costs, cognitive workload, lack of automation, and delays
- Enable mobility for anywhere, anytime, anybody with choices
  - New airspace uses and mobility options are emerging rapidly

Increased competition and future needs offer opportunity for better "Auto" based system